CLEANROOM ENERGY BENCHMARKING
SITE REPORT

FACILITY J
NORTHERN CALIFORNIA

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LAWRENCE BERKELEY NATIONAL LABORATORY

PREPARED BY:

99 LINDEN STREET
OAKLAND, CA 94607
WWW.RUMSEYENGINEERS.COM

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Project Team

Lawrence Berkeley National Laboratory

Bill Tschudi

Dale Sartor

Rumsey Engineers, Inc

Peter Rumsey

Achai Broner

Larry Chu

John Weale

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I. EXECUTIVE SUMMARY

As part of the California Energy Commission Public Interest Energy Research (PIER) project, energy use at Facility J was monitored May 3 to May 12, 2004. Facility J, built in approximately 2002, is a facility that houses primarily office spaces, cleanrooms and non-clean supports areas.

This site report reviews the data collected by the monitoring team and presents a set of performance metrics as well as a complete set of trended data points for energy end uses for equipment supporting and located in the cleanrooms. Some of the most important metrics are summarized below in Table 1.

Table 1. Cleanroom Metric Results for Facility J

Metric Name	Metric Value
Class 100 Recirculation Fan Efficiency	2,184 cfm/kW
Class 100 Make Up Fan Efficiency [1]	1,492 cfm/kW
Class 1,000 Recirculation Fan Efficiency	1,496 cfm/kW
Class 1,000 Make Up Fan Efficiency [1]	1,492 cfm/kW
Class 100,000 Recirculation Fan Efficiency	983 cfm/kW

1.   Make up air for the class 100 and class 1,000 cleanrooms are supplied by the same air handler, therefore, the metrics are identical.

The metrics for the HVAC systems at Facility J show that there are opportunities for energy efficiency improvement. The monitoring team observed a number of opportunities for potential energy savings at the facility. A summary of these observations follows and a more detailed discussion can be found in Section VI "Site Observations Regarding Energy Efficiency".

II. INTRODUCTION

Energy metrics were established that allow cleanroom owners to evaluate their energy efficiency performance and identify opportunities for improvements that reduce their overall operating costs. The project is administered by LBNL and funded through the California Energy Commission.

This Site Report summarizes the data collected and presents energy performance metrics with which the facility can evaluate the performance of its cleanrooms. First, the report reviews the site characteristics, noting design features of the mechanical plant and the cleanrooms monitored. Second, the energy use for the cleanrooms and mechanical equipment is broken down into components. Third, performance metrics recorded through the project are presented. Finally, key energy efficiency observations for the facility are noted. This is not intended to be a full energy audit, merely observations from the site measurement team. The data collected, trended graphs and methodology documentation are included among the appendices.

III. REVIEW OF SITE CHARACTERISTICS

A. Site

Facility J, located in Northern California, is a two-story 100,000 sf building that is approximately two years old. The building houses primarily cleanrooms, office spaces, and non-clean support areas, such as hallways and mechanical equipment rooms.

A 2,000 kW diesel generator provides backup power in the case of a utility failure. Backup power is supplied to the makeup and recirculation air handlers serving the cleanrooms, both chilled water plants, exhaust fans and lighting for life safety reasons, various process tools, and the fire alarm and telephone systems. Two uninterruptible power supply (UPS) systems are also utilized to provide emergency power. One UPS rated at 1000 kVA provides backup power to various process tools, life safety systems and automated controls systems. The second UPS rated at 15 kVA/10.5 kW provides emergency power to the makeup air handler serving the Class 100 area to keep the room pressurized to mitigate contamination during a utility power failure.

The environmental systems serving the cleanrooms run 8,760 hours a year in order to maintain conditions. The cleanroom spaces are conditioned by sixteen air handlers served by a chilled water plant, steam boiler plant, and steam humidifiers. A VAV (variable air volume) system consisting of one large rooftop air handler serves the office areas. The HVAC chilled water plant consists of two water-cooled chillers to provide chilled water to the make up air handlers (MUAH) and recirculation air handlers (RCU). The HVAC chilled water plant also serves process equipment; i.e. CDA compressor cooling, steam condensate coolers, clean steam generator, etc. Hot water is generated through a heat exchanger supplied with steam by the boiler plant. The hot water is distributed to the coils in the make up air handlers, and the VAV boxes serving the office areas. An additional water-cooled chiller plant is utilized for cooling of additional process manufacturing tools.

The cleanrooms chosen for monitoring are the Fill Suite Cleanroom (Class 100 - 885 sf), the Fill Suite Hall/Component Staging Cleanrooms (Class 1,000 - 740 sf), and the Parts Preparation/Loading/ Equipment Wash Cleanrooms (Class 100,000 - 1,805 sf).

Chilled water is produced by two water-cooled chillers connected by a common header. Normally, one chiller runs while the other stages on as necessary to accommodate the loads during warmer days. The chilled water system employs a primary-secondary loop pumping system. There are three constant speed pumps on the primary loop, and three variable-speed driven pumps on the secondary loop; two primary and two secondary pumps normally operate with one each on emergency backup. During the monitoring period, chilled water was supplied at $42.6 \pm 0.5°F$.

Process cooling water is supplied by two water-cooled chillers connected by a primary-secondary loop. There are three constant-speed pumps on the primary loop, and three variable-speed driven pumps on the secondary loop; two pumps on each loop normally run with the third on emergency backup. Process cooling water is used to cool the process equipment located in the cleanrooms.

There are two steam boilers, with one on emergency backup, used to generate hot water via a heat exchanger for use in the hot water coils of the make up air handlers. Hot water is also used for the VAV reheat coils serving the office and miscellaneous spaces. Hot water is distributed by one hot water pump with an additional pump serving as an emergency backup. A clean steam plant is also utilized for generating humidification for the air handlers, and for cleaning of the process equipment. There is a separate steam boiler system used to generate clean steam to serve the process tools and the humidifiers in some of the make up air handlers. Various cleanrooms are equipped with exhaust fans without scrubbers

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B. Fill Suite Cleanroom Design

The Fill Suite Cleanroom as measured in this report is a total of 780 sf, including both primary and secondary (air return) areas. The return area consists of 120 sf. The cleanroom utilizes a pressurized plenum and is rated at class 100. HEPA ceiling coverage in the cleanroom is 100% as mandated by the FDA. The Fill Suite cleanroom has low sidewall returns.

The Fill Suite Cleanroom is served by one make up air handler (AH-5340), and two recirculation air handlers (AH-5380 and AH-5381). The make up air unit delivers its air to the intake plenums of the RCUs. The make up air handler is served with chilled water, heating hot water and clean steam for humidification. The RCUs are served with chilled water only.

Make Up Air Handler, AH-5340

The environmental specifications for the cleanrooms are 65.5°F ± 5.5°F (18°C ± 3°C) and 45% ± 15% relative humidity. During the monitoring period, the measured temperature for the Fill Suite Cleanroom was 66°F ± 0.4°F, and the average measured relative humidity was 48% with a fluctuation of ± 6%.

C. Fill Suite Hall/Component Staging Cleanroom Design

The Fill Suite Hall/Component Staging Cleanrooms are class 1,000 cleanrooms. The Fill Suite Hall and Component Staging areas have local protection with 100% HEPA filter coverage; these areas are served by a pressurized plenum. The gowning room and de-gowning areas have 20% and 28% HEPA coverage, respectively; these areas utilize ducted HEPAs. The total cleanroom area, including both primary and secondary areas, is 870 sf. A wall physically separates the two cleanrooms. The cleanrooms are served by a recirculation air handler (AH-5360) and make up air handler, AH-5340, which also provides makeup air to the Fill Suite Cleanroom mentioned above. The cleanroom return air is directed through low sidewall returns around the perimeter of each of the cleanrooms. The air handling unit is served with chilled water and

Air Handler, AH-5360

heating hot water. and steam for humidification.

Table 2. Class 1,000 Cleanroom Areas

Cleanroom	Primary Area (sf)	Secondary Area (sf)	Total Area (sf)
Fill Suite Hall	265	35	300
Component Staging	105	15	120
Gown	240	20	260
De-Gown	85	10	95
Common Area	175	0	175
Total	870	80	950

The design specifications for the cleanroom air conditions are 68°F ± 9°F (20°C ± 5°C) and 45% ± 15% relative humidity. During the monitoring period, the measured temperature was 66°F ± 2°F, and the measured relative humidity was 51% ± 8%. The cleanroom temperature and humidity sensors may need to be calibrated.

D. Parts Preparation/Loading/Equipment Wash Cleanroom Design

The Parts Preparation/Loading/Equipment Wash Cleanrooms are class 100,000 pressurized plenum cleanrooms. The filter coverage varies throughout the rooms; areas of the Parts Preparation and Loading Cleanrooms each have local protection where HEPA coverage is 100% and air is supplied to a pressurized plenum. The average HEPA filter coverage for the Pats Preparation and Loading Cleanrooms is 39% and 44%, respectively. The air is ducted to HEPA filters for the areas without local protection. The Equipment Wash room has 11% HEPA coverage. The total cleanroom area, including both primary and secondary areas, is 1,420 sf. Physical walls of separation divide the rooms in this cleanroom area. The cleanrooms are served by a single air handler (AH-5320), which provides both makeup air and recirculation air. The cleanroom return air is directed through low sidewall returns around the perimeter of each of the cleanrooms. The air handling unit is served with chilled water and heating hot water. A steam humidifier will be installed for this unit in the future.

Table 3. Class 100,000 Cleanroom Areas

Cleanroom	Primary Area (sf)	Secondary Area (sf)	Total Area (sf)
Part Preparation	700	85	785
Loading	435	30	465
Equipment Wash	285	20	305
Total	1,420	135	1,555

The design specifications for the cleanroom air conditions are 72.5°F ± 13.5°F (22.5°C ± 7.5°C) without any relative humidity requirements. During the monitoring period, the measured temperature was 66°F ± 2°F, and the measured relative humidity was 51% ± 8%.

Table 4. Summary of Measured Cleanroom Air Handling Parameters

Description		Fill Suite	Fill Suite Hall/Component Staging	Parts Preparation/Loading /Equipment Wash [2]
		Class 100	Class 1,000	Class 100,000
Primary Area	sf	660	870	1,420
Ceiling Height	ft	9	9	9
Total Make Up Air [1]	cfm	956	3,967	8,695
Total Make Up Fan Power [3]	kW	3.3		20.1
Total Recirculation Air [1]	cfm	61,732	20,866	11,038
Total Recirculation Fan Power	kW	28.3	13.9	20.1
Room Air Changes per Hour	ACH	531	160	52
HEPA Filter Ceiling Coverage	%	100	varies, see description above	varies, see description above
Average Ceiling Filter Velocity [4]	fpm	115	52	26

1. *Make Up and Recirculation Air is the air delivered, based on the balance report data.*
2. *Make Up and Recirculation air for the Parts Preparation/Loading/Equipment Wash Cleanrooms are delivered by the same unit, therefore the power consumption is identical.*
3. *Make Up air is delivered to the Fill Suite Cleanroom and the Fill Suite Hall/Component Staging Cleanrooms by the same air handler.*
4. *Filter velocity based on average filter flow and 6.8 sf (85%) effective filter area.*

IV. SITE ENERGY USE CHARACTERISTICS

A. Cleanroom Power Consumption

The energy consumption attributed to the cleanroom air handling systems, exhaust fans, process tools, and lighting are reported in Tables 5, 6 and 7. This breakdown of energy use by equipment helps identify the major loads.

Table 5. Fill Suite Cleanroom Power Consumption Breakdown

Description	Average Load (kW)	Average Efficiency
AIR HANDLING		
Make Up Fans	3.3	1,492 cfm/kW
Recirculation Fans	28.3	2,184 cfm/kW
EXHAUST FANS [1]	N/A	N/A
PROCESS POWER [2]	-	-
LIGHTS [3]	0.5	0.75 W/sf
TOTAL	32.1	

1. *Cleanroom does not utilize exhaust fans.*
2. *Process tools were not being used during monitoring period since cleanroom was not fully operational.*
3. *Lighting power calculated based on lighting power density of a representative cleanroom.*

Table 6. Fill Suite Hall/Component Staging Cleanroom Power Consumption Breakdown

Description	Average Load (kW)	Average Efficiency (cfm/kW)
AIR HANDLING		
Make Up Fans [1]	3.3	1,492 cfm/kW
Recirculation Fans	13.9	1,496 cfm/kW
EXHAUST FANS	1.8	3,403 cfm/kW
PROCESS POWER [2]	-	-
LIGHTS [3]	0.65	0.75 W/sf
TOTAL	19.7	

1. *The make up air handler also serves the Fill Suite Cleanroom, therefore, the values are identical to the table above.*
2. *Process tools were not being used during monitoring period since cleanroom was not fully operational.*
3. *Lighting power calculated based on lighting power density of a representative cleanroom.*

Table 7. Parts Preparation/Loading/Equipment Wash
Cleanroom Power Consumption Breakdown

Description	Average Load (kW)	Average Efficiency (cfm/kW)
AIR HANDLING		
Make Up/ Recirculation Fans [1]	20.1	983 cfm/kW
EXHAUST FANS [2]	N/A	N/A
PROCESS POWER [3]	-	-
LIGHTS [4]	1.1	0.75 W/sf
TOTAL	21.2	

1. *Air handing unit provides both make up and recirculation air.*
2. *Cleanroom does not utilize exhaust fans.*
3. *Process tools were not being used during monitoring period since cleanroom was not fully operational.*
4. *Lighting power calculated based on lighting power density of a representative cleanroom.*

B. Electrical System Power Consumption

The table below shows the power consumption of the emergency generator standby power loss. The emergency generator constantly draws power to maintain the batteries and a specific temperature of the diesel engines that drive the generator. The generator has a capacity of 2,000 kW.

Table 8. Electrical System Power Consumption

Description	Average Load
ELECTRICAL SYSTEM	
Emergency Generator Standby Power	5.3 kW

V. SYSTEM PERFORMANCE METRICS

Metrics are ratios of important performance parameters that can characterize the effectiveness of a system or component. In order to gage the efficiency of the entire building system design and operation, this project tracks key metrics at different system levels. These metrics can be used to compare designs or determine areas with the most potential for improvement via retrofit or replacement.

For Facility J, the cleanroom HVAC components operate at a nearly constant level throughout the year. Therefore, these metrics are based on spot measurements. All of the metrics involving area are based on the primary cleanroom area, which is the area that passes certification, unless otherwise noted.

The Fill Suite Cleanroom is class 100. The pressurized plenum recirculation air handling efficiency was 2,184 cfm/kW. The recirculation air handling efficiency is poor, when compared to other pressurized plenum cleanrooms of various class ratings with an average efficiency of 5,152 cfm/kW. The cleanroom air change rate for this cleanroom is relatively high for this class of cleanroom. While the air change rate

is high within the set of Class 100 facilities benchmarked, it does fall within the range recommended by other sources (see http://cr.pennnet.com/Articles/Article_Display.cfm?Section=Archives&Subsection=Display&ARTICLE_ID=165797 for a copy of CleanRooms Magazine article discussing this issue). The benchmarking project has found that significantly lower air change rates are commonly used to provide the same class cleanroom environment, and with the good gowning protocol observe it is expected that a lower rate could be used without problem. A reduction to a level of 250 - 300 ACH should be investigated to further reduce energy usage.

Table 9. Cleanroom Metrics

Description		Fill Suite Cleanroom	Fill Suite Hall/Component Staging Cleanrooms	Parts Preparation/Loading /Equipment Wash Cleanrooms [3]
		Class 100	*Class 1,000*	*Class 100,000*
MUAH Efficiency	cfm/kW	1,492		983
Make Up Air	cfm/sf	1.4	4.6	6.1
Make Up Fan Power Density [1]	W/sf	2.2		14.1
Recirculation Air Handler Efficiency	cfm/kW	2,184	1,496	983
Recirculation Air	cfm/sf	79.7	32.1	6.1
Recirculation Air Changes per Hour	ACH	624	160	52
Recirculation Fan Power Density [1]	W/sf	42.8	16.0	14.1
Lighting Power Density	W/sf	0.75	0.75	0.75
Process Tools Power Density [2]	W/sf	not measured	not measured	not measured

1. *Calculated as total kW load divided by the primary area of the cleanroom.*
2. *Process tool power load was not measured since the facility was not in production.*
3. *Air handlers for the Parts Preparation/Loading/ Equipment Wash Cleanrooms provide both make up and recirculation air, therefore the data is identical for the make up air handler and recirculation air handler.*
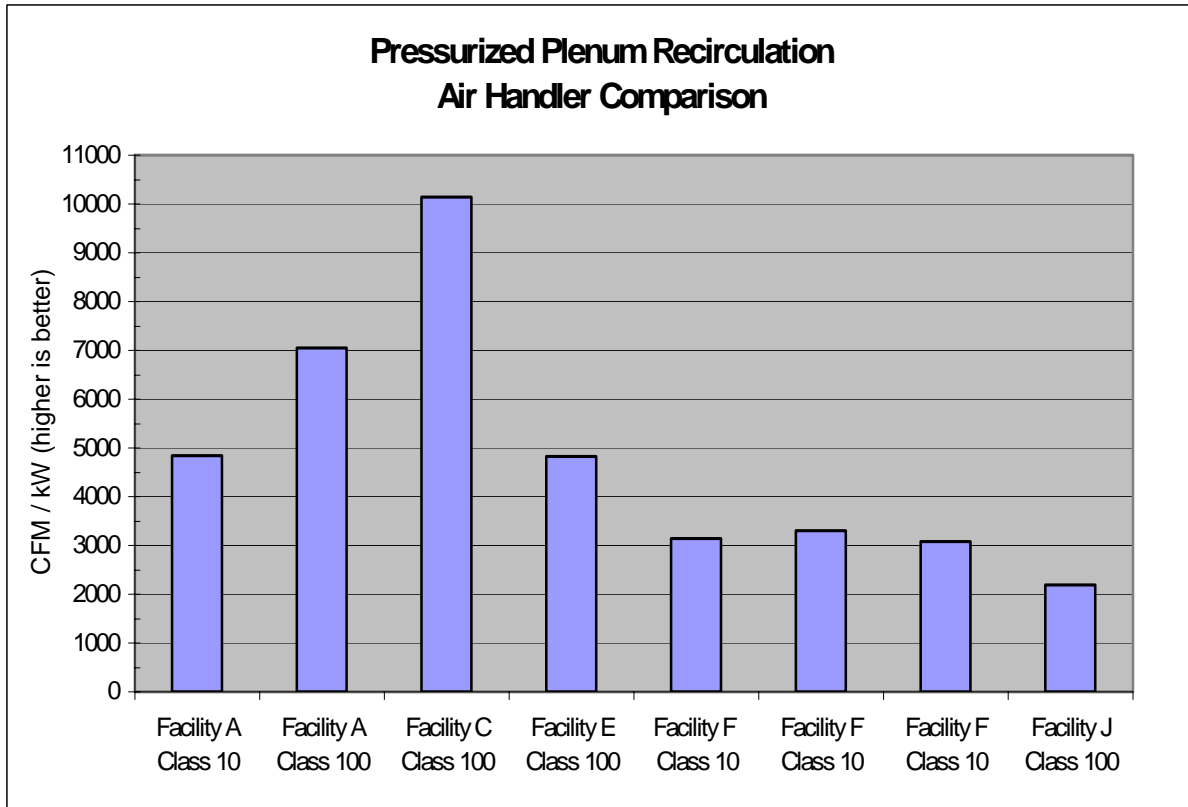
Figure 1. Pressurized Plenum Recirculation Air Handler Efficiencies of Measured Facilities (Various Class Ratings)
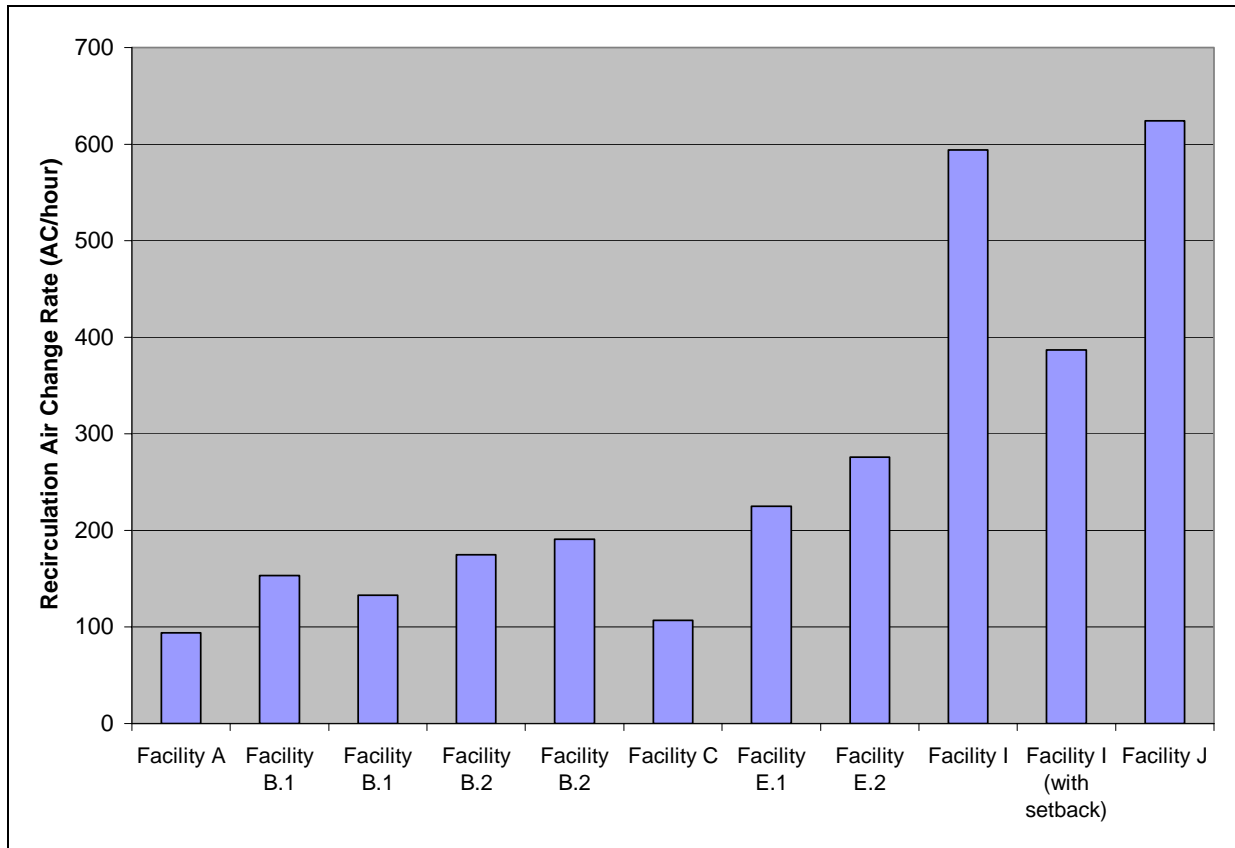
Figure 2. Recirculation Air Change Rate of Measured Class 100 Cleanrooms

VI. SITE OBSERVATIONS REGARDING ENERGY EFFICIENCY

Raise Chilled Water Supply Temperature

The 36°F low temperature loop could be reset to a higher temperature. Low temperature chilled water is inherently more energy intensive to produce due to the larger temperature delta, or 'lift,' the compressor is required to move heat through. On centrifugal compressors based chillers, an increase of one degree in the chilled water supply temperature improves the efficiency of the chiller by 1 to 2%. The chiller manufacturer should be consulted before radical modification of the supply temperature, but a change of a few degrees should allow for an improvement in efficiency without risk.

Condenser Water Temperature Reset

The chillers in the main plant may also benefit from a reduction in lift in two different ways. The first would be to ensure the condenser water reset is working properly and verifying with the factory that it cannot be taken lower. A reduction in the condenser water temperature of a couple degrees will achieve meaningful energy savings, however chiller stability can be compromised if it is taken too low, hence the need to verify with the chiller manufacturer before modifying this point.

Chilled Water Temperature Reset

The other way to improve chiller performance is to implement a chilled water temperature reset. When dehumidification is *not* required, there is typically a significant surplus of coil capacity. This allows the chilled water temperature to be increased, improving the chiller efficiency. There are a number of chilled water resets that have been shown to work. The simplest is to set the CHW temperature based on the outside air temperature, with the lowest temperature chilled water setpoint achieved during the highest outside air temperatures and during dehumidification. A more sophisticated approach is to poll all the chilled water valves on the loop for their position. If no valve is at 90% or more open, then maximum cooling is not required and the chilled water temperature can be increased. When a valve position exceeds 90%, it indicates a space is calling for additional cooling and the chilled water temperature can be reset down. The savings from a chilled water reset are maximized when the periods of dehumidification are minimized.

Operate Cooling Towers in Parallel

The lowest energy operation of a cooling tower is when heat is rejected without the use of any fan power, with air driven strictly by natural convective forces. To achieve this type of operation, the amount of surface area being wetted should be maximized. As many towers as possible should be operated simultaneously. The number of towers in operation is limited typically by the minimum flow that allows the tower nozzles to sufficiently achieve even tower media wetting.

Relative Humidity Control

The humidification setpoint is more restrictive than the specification requires. Loosening the humidification setpoint can reduce the hours of humidification/dehumidification in this very mild climate. Controlling the humidity levels in the supply air is very energy intensive; the fewer hours of control, the lower the overall energy cost.

The current humidification control algorithm appears to have stability problems. Since humidity control is so energy intensive, control instabilities can consume significant amounts of energy during unnecessary overshoot. The stability of the space conditions can also suffer. It is recommended that the pychrometric parameter 'Dewpoint Temperature' be used instead of RH for supply air humidity control loops. Control to RH tends to be prone to control problems due to the volatility of the RH reading – the RH of air changes quickly in response to both temperature changes and changes in the quantity of water in the air. The dewpoint changes only in response to changes in the quantity of water in the air, providing a more

direct measurement point for humidification loops. The space should still be controlled to RH, since RH is typically the parameter of interest in interactions with cleanroom activities and workers.

Steam-in-place Heat Recovery

The SIP, steam-in-place, process for cleaning tanks may offer some energy saving opportunities. During the SIP process, the tank is increased in temperature to a point higher than the hot water loop using clean steam. The tank is then cooled using compressed air, at an energy cost of about 200 watts per cfm, until it is cool enough to use chilled water in the jacket for final cooling. This process takes significant time, and also uses energy intensive compressed air just to reject heat to the room, where it then has to be removed through the chiller system. There is an opportunity to use the *hot water* loop for the initial stages of cooling. Using the hot water loop would reduce the use of compressed air as well as actually recover some of the tank's heat into the hot water loop for use elsewhere in the facility. The amount of heat recovered could be optimized by lowering the hot water loop temperature as much as is permissible.

Uninterruptible Power Supply (UPS) System Efficiency

Most uninterruptible power supply systems operate more efficiently when they are more heavily loaded. The efficiency of a battery UPS tends to decrease significantly when it is loaded at 30% or lower. See the figure below. Properly sizing a UPS system will minimize the energy losses. In addition, adding non-critical circuits to the UPS to increase its load may also be a strategy to decrease the overall power consumption of the facility.
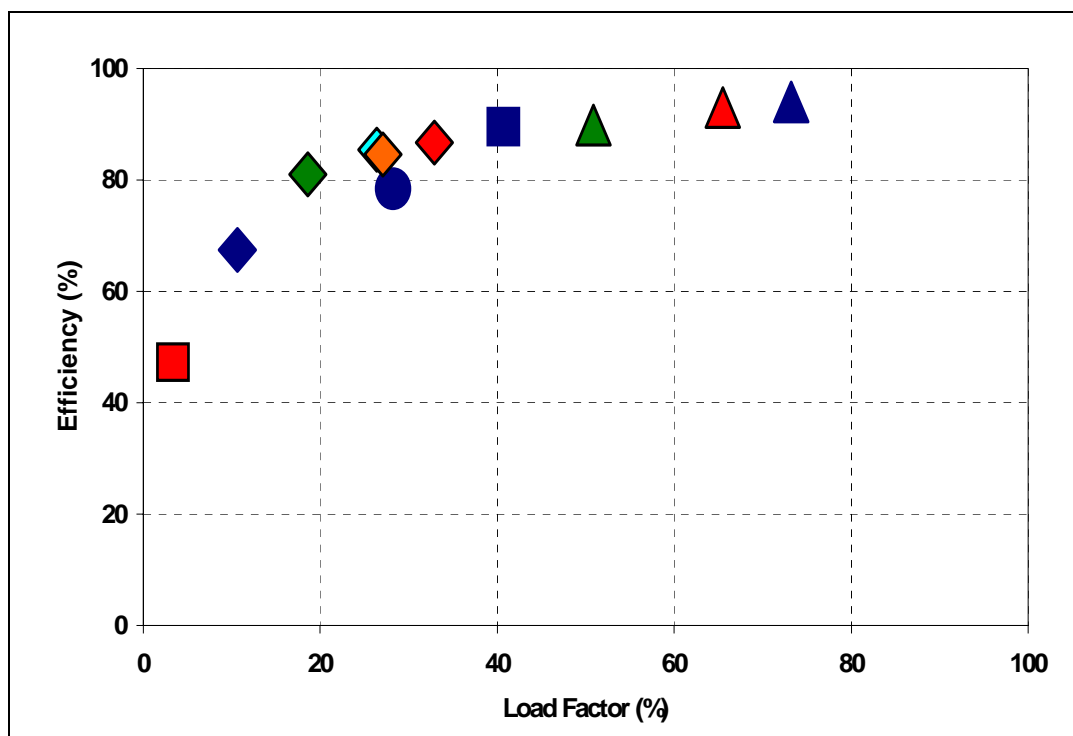

Figure 3. UPS Efficiency